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The Impact of Industrial Sites on Residential Property Values

A hedonic pricing analysis for the Netherlands

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Abstract
Industrial sites cause several negative externalities, such as traffic noise disturbance, congestion, and obstruction of view. In order to quantify the negative effects stemming from industrial sites, we estimate – using a hedonic pricing model – the impact of distance to industrial sites on residential property values. We use data on houses sold in the Randstad region and the province of Noord-Brabant (both located in the Netherlands) in the year 2005, together with data on characteristics of a substantial number of industrial sites in the same regions and period. The results reveal that the distance to an industrial site has a statistically significant negative effect on the value of residential properties. However, the effect is largely localized within a relatively short distance from the nearest industrial site. Furthermore, we obtain statistical evidence for substantial localized price differentials, which vary according to the size of an industrial site.

Keywords: industrial sites, negative externalities, hedonic pricing

JEL codes: O18, R30, R52

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1. Introduction

Results of Dutch policies aimed at providing an adequate supply of industrial land are mixed. In accordance with the spatial policy objectives, industrial sites have become the main location for supplying industrial land. Slowly but steadily the amount and share of employment on industrial sites is rising. Industrial sites have become a favourable place to settle for many firms (Louw and Bontekoning, 2007). It appears that industrial sites can be considered as important contributors to the (local) economy: industrial sites in the Netherlands cover about 2 per cent of the total Dutch area, whereas they account for about one-third of the national output (Louw et al., 2007). However, the recent planning debates about industrial sites in the Netherlands have given much attention to the quality of industrial sites (Louw et al., 2004). Concerns have been raised about the possible negative external effects of industrial activities on other firms, on nature and in particular on households (Schuur, 2001; Needham and Louw, 2003; Louw et al., 2004; Blaauw, 2007). Although the development of industrial sites in the Netherlands is based on the mono-functional policy concept of separating industry and housing, residents may be affected by industrial sites due to a multitude of perceived disamenities, such as noise, traffic, congestion, air pollution and obstruction of view.

This study contributes to the planning debate by elaborating on the implications of the presence of industrial sites on its direct vicinity. It aims to measure the negative externalities stemming from industrial sites and to get insight into the scope of these externalities as a tool for valuating the quality of an industrial site. By means of a hedonic pricing analysis of residential property transactions, we identify the impact – ceteris paribus – of the distance to industrial sites on property transaction prices. Furthermore, we look into the implications of the characteristics of an industrial site on the magnitude of its impact by differentiating according to the size of the industrial site concerned. Many existing studies dealing with the topic of negative externalities generated by industrial sites consider a specific, tightly framed, study area comprising a restricted number of industrial sites. These studies arrive at a multitude of outcomes referring to a ditto variety of specific cases.[1] In this respect, our study deviates from this literature by employing a more general approach: we analyze a comprehensive sample of industrial sites and the effects of these sites on neighbouring housing prices in the Randstad region and the province of Noord-Brabant (both in the Netherlands).

The paper is organized as follows. In Section 2 we discuss the literature on negative externalities originating from industrial facilities and hedonic pricing. Section 3 reviews the Dutch (policy) context with regard to the negative external effects of industrial sites. In Section 4 we present the characteristics of the data set underlying our analysis and the research set up. Section 5 sets out and discusses the employed econometric model. In Section 6 we present estimation results. Section 7 concludes.

[1] See, for example, Zeiss (1999) who elaborates upon the results of 69 studies dealing with the negative effects of industrial facilities on their direct vicinity.

2. Literature review

Farber (1998) provides a survey of the literature on the impact of undesirable facilities on house values due to perceived disamenities. Such concerns range from concerns about health risks to the public image of the community. They can manifest themselves in property markets since it is most likely that people are willing to pay more to reside in locations further located from perceived disamenities. The survey confirms that undesirable facilities (e.g., landfills, waste sites, hazardous manufacturing facilities) reduce property values in their direct vicinity. These adverse effects diminish with distance, resulting in increased property values as distance from these sites increases. Moreover, these adverse property value effects appear to be relatively localized. Other examples can be found in a number of studies which have shown effects on property values due to a contaminated site. These studies (e.g., Smolen et al., 1991; Mendelsohn et al., 1992) have reported adverse impacts on values ranging from as low as 0.24 per cent to as high as 25 per cent, depending on the extent of pollution and the location of the property. In view of the Dutch situation, Visser and Van Dam (2006) have analyzed the housing market in the Netherlands as a whole and have focused, among other things, on the contribution of environmental characteristics to housing price variation. By taking into account various characteristics within the direct vicinity (50 metres) of the dwelling concerned (e.g., presence of parks, open space and industrial land, nature and quality of buildings, social status of the neighbourhood, distance to services, and infrastructure), they conclude that property value is positively affected by the quality of its vicinity in terms of availability of amenities. For instance, houses, located in low-dense, green neighbourhoods, are significantly higher valued than houses in high-dense areas with a lack of parks and open space. Conversely, disamenities, like the presence of industrial land and highway nearness, affect the prices negatively. These findings suggest that effects stemming from (dis-)amenities operate especially on a local scale, which confirms the notion that impact attenuates with distance. These outcomes are confirmed by the more detailed studies concerning the Dutch situation of Rouwendal and Van der Straaten (2008) Dekkers and Van der Straaten (2008) and Debrezion et al. (2006). The first shows that, in three major Dutch cities (Amsterdam, Rotterdam and The Hague), parks and public gardens within the vicinity of a house increase its value. However, due to the tight housing market situation in Amsterdam, the willingness to pay for open space is lowest in this city, as compared to the other cities considered. The second study investigates the effect of aircraft noise on house prices in the highly urbanized area around Amsterdam Airport. Controlling for multiple sources of traffic noise, air traffic yields the largest price impact, followed by railway traffic and road traffic. Finally, Debrezion et al. (2006) analyze the effect of accessibility provided by Dutch railway stations on residential housing prices. The study shows that housing price attenuate with distance to a railway station, exposing a positive effect of proximity. This effect is enhanced when the frequency of train services on a station increases. Hence, these studies provide insights in the efficiency of public policy in terms of optimal open space provision, aircraft noise reduction measures and railway station accessibility, respectively.

As the existing literature has mainly focussed on cataloguing the adverse effects on property values, less is known about the magnitude with which the property values may increase following a cleanup or remediation of a site. Exceptions are Dale et al. (1999) and McComb (2004) who report that property values around the sites under investigation appeared to be lower before the cleanup or remediation. However, after the cleanup, the prices consistently rebounded, although the areas closest to the site and the poorest neighbourhoods rebounded more slowly. These studies underline that taking into account specific properties of sites may increase the accurateness of the impact effects.

The previously mentioned studies are useful in demonstrating the nature and intensity of the impact of local forms of land use. Generally, they are based on revealed preference methods to observe what individuals really pay or require in compensation for living in the vicinity of sites generating negative externalities (Farber, 1998). Hedonic pricing methods are helpful to identify the impact of the various externalities (Rosen, 1974). Hedonic prices are defined as the implicit prices of attributes, which are revealed to economic agents from observed prices of differentiated products and the specific amounts of characteristics associated with them. More specifically, in hedonic price analysis, housing prices are regressed on a vector of inherent attributes. A hedonic equation helps to explain housing prices in terms of the house's own characteristics, such as the type of dwelling, age, floor-area, neighbourhood characteristics and job accessibility. Each of these attributes is assumed to be implicitly priced. The real estate literature is replete with hedonic pricing models estimating the willingness to pay for housing characteristics (e.g., Linneman, 1981, and Parsons, 1981). In addition, there has been a growing literature that uses the hedonic pricing model to measure the impact of environmental amenities and disamenities on real estate values (e.g., Kohlhase, 1991, Hite et al., 2001, Kiel and Zabel, 2001, and Kaufman and Cloutier, 2006).

However, hedonic pricing methods face some limitations (Farber, 1998; Kiel and Zabel, 2001). First, property markets may not be in equilibrium when the impact of the undesirable facility is estimated. This is why one would ideally prefer to use data on house sales over a sufficiently long period of time. Second, there is an inherent problem in statistically identifying the willingness to pay to avoid a disamenity. Selectivity plays a strong role in residential location decisions. When persons most willing to accept a disamenity, or who have limited housing options because of income or discrimination, they locate adjacent to a disamenity. As a consequence, property value differentials will underestimate the disamenity effect for the general population. Third, to the extent that the adverse activity may be locally job enhancing, adjacent house values could be elevated because of positive wage effects associated with the land use. Although there could still be a negative amenity component, it may be offset by a positive wage effect. Despite these limitations which are important to be kept in mind when interpreting results from hedonic pricing models, the model is well-applicable to identify the scope of negative externalities industrial sites by revealing the effect of distance to industrial sites on residential property values.

3. The Dutch context

Like in many Western countries, post-war spatial planning in the Netherlands has been dominated by mono-functional approaches. This has resulted in core spatial functions, such as housing, industry, farming, or shopping, being allocated to rather large-scale areas, often separated by 'buffers of open space'. However, several studies and the proliferation of 'mixed land use' approaches have revealed the limitations of mono-functional land use (Lagendijk, 2001; Vreeker et al., 2004). Whereas concepts of mixed land use aim to reduce urban sprawl and to promote spatial and environmental quality, the mono-functional approach presents a rather space-consuming form of land use which also tends to be inferior in terms of spatial quality. This notion is to a large extent in accordance with the Dutch case of the provision of industrial sites which is characterized by an abundant availability of industrial land and an associated decline of spatial quality (Gordijn et al., 2007).

In the Netherlands, local authorities are the main suppliers of building land, whether for housing or industry. On account of their statutory planning and land policy powers, they can plan and develop industrial sites[2,3] or facilitate enterprise zones. Therefore, the role of private agents in the supply of industrial land has always been limited; approximately 74 per cent of the total area of industrial land is supplied by local authorities (Segeren et al., 2005). Local authorities consider the provision of industrial sites as a key instrument of their economic policy. In accordance with their task and responsibility as industrial land provider, local authorities ensure that there is always a minimum amount of industrial land available for immediate sale to interested companies. Over the last decade, this approach has resulted in a yearly average disposal of 1,038 hectares of industrial sites. The stock of industrial sites in the Netherlands has increased from 3,203 formal industrial sites in 1995 to 3,605 sites in 2006. This represents an increase from 78,886 hectares to 94,560 hectares (Arcadis and Stec Groep, 2007). It implies a rise of industrial land coverage from 1.3 per cent to 2.7 per cent as share of the total Dutch area. Given the growth rate of land designated for housing (8.0 per cent in the period 1993 to 2000) we can infer that industrial land has risen substantially with 12.9 per cent in the same period (Gordijn et al., 2007).

An important side-effect of the ample provision of industrial land, besides a shrinking quantity of open space, is the corrosion of environment and landscape. This does not only refer to the obstructing consequences of the disposal of new industrial land, but also to its contribution to the process of ageing of existing industrial sites. According to the Dutch Industrial Sites Database (Arcadis and Stec Groep, 2007), 29 per cent of the total number of industrial sites (1,052 sites) was considered as 'out-dated' in 2006. These sites are faced with substantial vacancies in the building stock and poorly maintained public spaces. Being attracted by the favourable circumstances of recently serviced land, well-performing companies move to newly developed industrial sites. As a result, this outflow of well-performing firms generates unused industrial premises and substitution by

[2] In general, an industrial site can be considered as a collective location for the establishment of firms (Bak, 1985).
[3] Sites that are designated exclusively for offices are not covered by this definition.

marginal firms which creates a downward spiral of attractiveness of the concerned existing industrial sites (Louw and Bontekoning, 2007).

Concluding, the 'buffers' of open space are under pressure in the Netherlands. This involves a gradual diminishing of remoteness of housing and other functions to industrial sites. Accordingly, the suggested application of mono-functional planning, and the interplay between distance and perceived negative externalities, provides us with a relevant background with regard to the impact of negative externalities originating from industrial sites, to which we turn in the remainder of this paper.

4. Data set and research set up

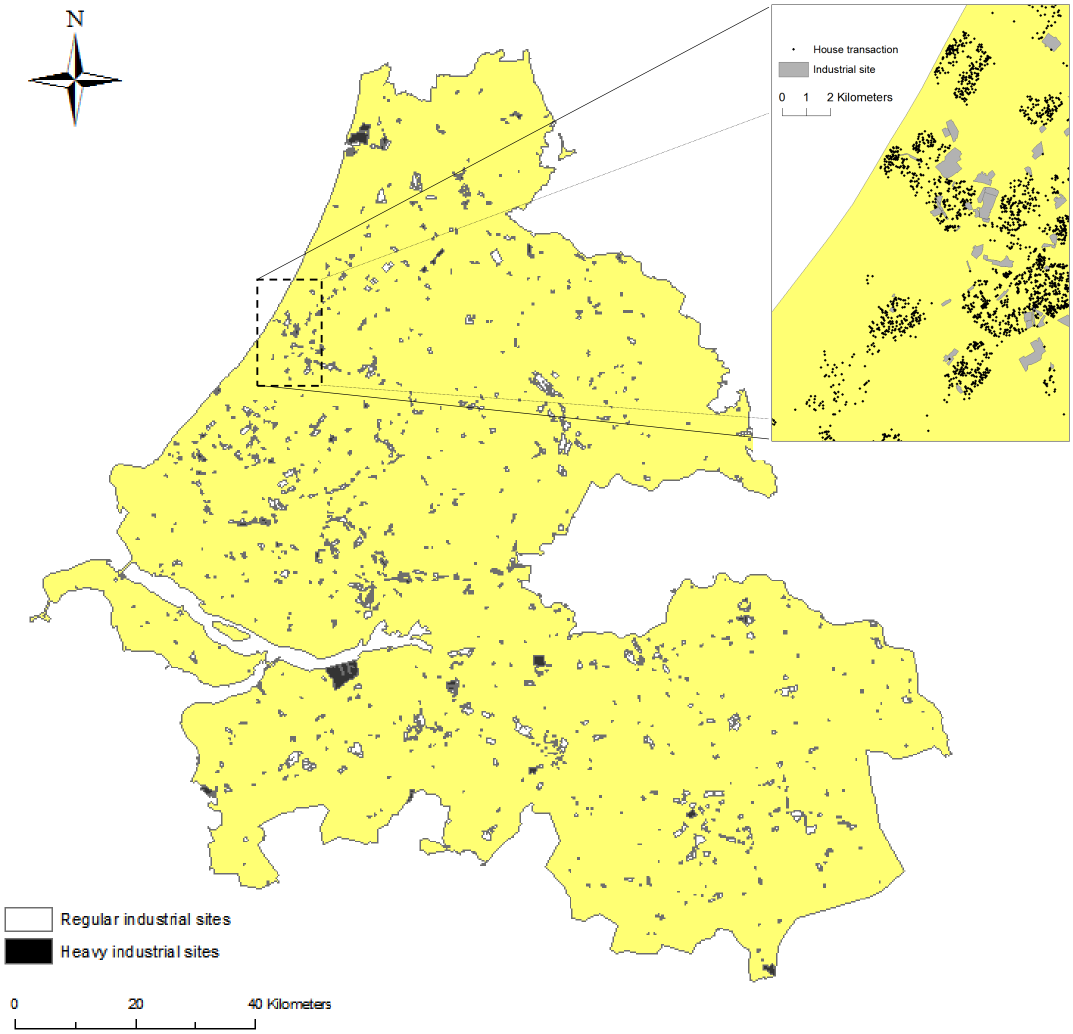
The prime data originate from two sources: industrial site data are collected from the Dutch Industrial Sites Database (IBIS) and property data are collected from the Dutch Association of Real Estate Agents (NVM). The selected data refer to the Randstad region[4] and the province of Noord-Brabant in the Netherlands in the year 2005. The collected data on industrial sites and houses are all geo-referenced, which enables us to link these sets by using GIS (see the detailed map in Figure 1).

Since the Randstad region and Noord-Brabant are jointly responsible for generating 51 per cent of the total Dutch GDP, these regions are considered as the economic core-regions of the Netherlands. Respectively, 41 per cent and 15 per cent of the Dutch population resides in the Randstad region and Noord-Brabant (Statistics Netherlands, 2008). The regions studied comprise a considerable amount of the national stock of industrial sites. We employ a 500 metres buffer to the initial study area to incorporate possible effects stemming from industrial sites located just outside the examined region. Hence, we obtain a sample containing information on 1,201 industrial sites,[5] acquired from the Dutch Industrial Sites Database (IBIS). These sites cover 26,703 hectares of industrial land. Figure 1 displays the spatial distribution of the industrial sites in our sample.

[4] The Randstad region comprises the following areas: the province of Noord-Holland (excluding Alkmaar and surrounding area and the northern part of Noord-Holland) and the provinces of Zuid-Holland and Utrecht. We refer to Rietveld and Wagtendonk (2004) for more details about regional definitions.

[5] The examined area originally comprises 1,718 industrial sites. Due to data limitations regarding the variable 'type of industrial site', we have only selected 1,201 sites which do provide information on 'type of site'.

Figure 1. Distribution of industrial sites in the Randstad and Noord-Brabant, 2005



Source: Dutch Industrial Sites Database (IBIS)

The IBIS database provides an inventory of formal industrial sites[6] providing information on numerous characteristics of the industrial sites concerned, of which the variables location and 'type of industrial site' are the most relevant for the purpose of this paper. Regarding the variable 'type of site', the IBIS data set distinguishes five categories of industrial sites: 'heavy-industry', 'sea-harbour', 'miscellaneous', 'high-tech' and 'transport'. This typology of industrial sites is associated with the

[6] An industrial site is defined as 'a location of which the land-use plans deem suitable for activities in the branches of commerce, manufacturing, commercial services, industry and which original design is larger than one hectare'.

nature of an industrial site;[7] it proxies the quality of the industrial sites concerned (Arcadis and Stec Groep, 2007). However, the typology faces a serious drawback in terms of distinctive capacity. In 2006, 60 per cent of the total amount of industrial area in the Netherlands (in hectares) has been marked as 'miscellaneous'. The categories 'heavy-industry', 'sea harbour', 'high-tech' and 'transport' represent, respectively, 10 per cent, 18 per cent, 4 per cent and 4 per cent of the area. The remaining 4 per cent of industrial land has been categorized as 'unknown' (Arcadis and Stec Groep, 2007). We deal with this drawback by categorizing industrial sites in two classes to proxy the nature of an industrial site. 'Heavy industrial sites' are sites which are originally classified as heavy-industry, sea harbour, and transport sites, as these types of sites are assumed to generate substantial nuisance in terms of noise, traffic, congestion and pollution. The category 'regular sites' comprises miscellaneous and high-tech sites. These sites are expected to create less nuisance than 'heavy sites'. In our sample, there are 61 sites categorized as 'heavy' and 1,140 sites as 'regular', covering, respectively, 728 and 25,975 hectares of industrial land.

The data regarding residential property values include information on all houses sold by NVM real-estate-agents[8] in the Randstad and Noord-Brabant in the year 2005. We have removed all observations referring to a house with a volume less than 100 m^3, a floor area less than 40 m^2 and a transaction price exceeding one million euros. Furthermore, the upper and lower 0.5 per cent of transaction values of the remaining observations has been excluded (see Rouwendal and Van der Straaten, 2008). This leaves a sample containing information on 70,684 dwellings within the defined area.

Furthermore, additional geographical information on important control variables like the ethnic composition and population density of the neighbourhood, location of highway exits and railway stations, and distance-to-jobs has been acquired from, respectively, Statistics Netherlands (CBS), the National Road Database (NWB), the Dutch Railways (NS) and the Netherlands Institute for Spatial Research (RPB)/Land Use Scanner.[9]

Building on the hedonic valuation methodology, and allowing for its limitations, described in Section 2, we assume that residential property values are a function of structural, neighbourhood and industrial site variables.[10] The structural variables are the physical characteristics or attributes of the residential property and include the numerical variables floor area and volume. Categorical variables

[7] Heavy-industry sites are industrial sites which intend to establish highly undesirable facilities in terms of environmental nuisance (e.g., landfills, demolition dumps, waste sites, hazardous manufacturing facilities, etc.). Sea harbours comprise large-scale sites featuring freight facilities for maritime shipping activities. Miscellaneous sites are commonly seen as regular industrial sites which include a large variety of activities (ranging from small to medium polluting activities), on the condition that these sites may not be categorized as high-tech or transport. High-tech sites are sites which are developed for high-tech production activities and R&D-activities. Transport is characterized by dominant presence of logistics and wholesale activities.

[8] NVM real-estate-agents cover for approximately 70 per cent of all property transactions in the Netherlands.

[9] These data sets have been provided by SPINLab, VU University Amsterdam.

[10] Rents are controlled in the Netherlands, implying that their values are determined by a restricted system of points that highly disregards neighbourhood characteristics. We therefore do not take into account rental housing in our analysis.

indicate the presence of central heating, garage and garden, the year of construction and the type of house. The latter incorporates four basic architectural house styles: free-standing, semi-detached, terraced house and apartment.

The neighbourhood variables cover the characteristics of the area in which the property is located, like socioeconomic factors, status of the area, ease of accessibility and labour market characteristics. We include the ethnic composition (fraction of ethnic minorities) and the population-density of the 4-digit ZIP-code area in which the dwelling is located. Additionally, a regional dummy is included to indicate the region (Randstad or Noord-Brabant) in which the dwelling of interest is located. We control for the ease of accessibility is two ways. First, we employ the ease of accessibility by road, operationalized by the road distance (metres) from each property to the nearest highway exit. Second, we employ the ease of accessibility by railway, operationalized by the straight-line distance (metres) from each property to the nearest railway station. Allowing for positive effects associated with the provision of local employment by the industrial site concerned, which may elevate adjacent house values, we include the minimum distance (circle radius in metres) within which a total of 100,000 jobs can be reached. This measure is a proxy for job opportunities in the vicinity of the house.

Industrial site variables refer to the perceived impact of industrial sites that are present. This variable encompasses the characteristics of the industrial sites which are located in the vicinity of the properties concerned. The location of an industrial site, vis-à-vis residential properties, is specified by the distance from the approximate centre of a residential property to the nearest industrial site. In this respect, we include the straight-line distances in metres from each residential property to the closest point on the boundary of the industrial site. A dummy variable is included to indicate the category (heavy or regular) to which this nearest industrial site belongs. Furthermore, we assume that the size of an industrial site matters in explaining impact on property values. Thus, we additionally control for the gross area[11] in hectares of the industrial sites concerned. Finally, since the data set also contains information about the date of house transactions, we include monthly dummies to capture effects of seasonality of the housing market. Appendix A reports the variable names, their sources, definitions and some descriptive statistics.

[11] Gross area is defined as the total area designated as industrial site, inclusive the area which is used for infrastructure, water, green space and other forms of public open space.

5. The econometric model

A formal way of describing the hedonic price function is as follows:

$$P_j = f\ (S_1,...,S_K; N_1,...,N_L; I_1,...,I_M; D_1,...,D_N), \tag{1}$$

where houses are indexed with j, P_j is house transaction price, and f relates the transaction price to structural (S) and neighbourhood (N) characteristics of the property, and characteristics of the industrial sites (I) concerned. Since the effect of distance to industrial sites on property transaction prices is our variable of key interest (D), we distinguish this variable explicitly. It assumes a housing market in equilibrium, meaning that, all individuals have made their utility-maximizing choices given the prices of alternative housing locations. For individual i living in house j the utility is given by (see Rosen, 1974):

$$u_i = u(x; S_1,...,S_K; N_1,...,N_L; I_1,...,I_M; D_1,...,D_N), \tag{2}$$

which is assumed to be strictly concave. x is all other goods consumed. Set the price of x equal to 1 and measure income of individual i, y_i, in terms of units of x. This gives the following budget constraint:

$$y_i = P_j(S_1,..., S_K; N_1,..., N_L; I_1,..., I_M; D_1,..., D_N) + x\ . \tag{3}$$

Maximization of utility subject to the budget constraint requires choosing x and $(S_1,...,S_K; N_1,...,N_L; I_1,...,I_M; D_1,...,D_N)$ to satisfy the budget and the first-order conditions. So, partial differentiation with respect to, for example, an industrial site attribute M gives the marginal implicit price for that attribute $\partial P_j / \partial I_M$.

Economic theory provides little guidance regarding choice of functional form for the hedonic price function (Deaton and Hoehn, 2004; Neupane et al., 2007). The double natural log specification is widely employed for model estimation (Freeman, 1993), largely motivated by the fact that it allows for a simple interpretation of estimated coefficients as elasticities. However, in order to describe the pattern of distance-decay, we measure the effect of distance on housing prices by using distance dummies, i.e. a less restrictive functional form instead of employing the natural log of distance. We use distance categories with a 250 metres range to enable us to examine the effect in a detailed way (see Debrezion et al., 2006). Endogenous determination of the cut-off distance by running models with different cut-off distances, results in a distance of 2,250 metres to the nearest industrial site beyond which housing prices are no longer significantly affected by negative externalities stemming from the industrial sites concerned.[12] As a consequence, the piecewise specification of distance renders nine categories up to 2,250 metres. In the empirical application, the transaction price of a house *j* is modelled as follows:

$$LnP_j = \alpha + \sum_{k=1}^{15} \beta_k S_{j,k} + \sum_{l=1}^{6} \gamma_l N_{j,l} + \sum_{m=1}^{2} \delta_m I_{j,m} + \sum_{n=1}^{9} \xi_n D\_dum_{j,n} + \varepsilon_j \,, \tag{4}$$

where all variables defined as in Equation (1). α is a constant, β, γ , δ and ζ are coefficients to be estimated. The variables of structural, neighbourhood, industrial site characteristics, and the distance-to-site variable for property *j* are, respectively, indexed by *k*, *l*, *m* and *n.* In accordance with the majority of the previous literature (see Section 2), Equation (4) is estimated by ordinary least squares (OLS). White's heteroskedastic consistent covariance matrix is used to correct the estimated errors for unknown forms of heteroskedasticity.[13]

In our model in its simple and basic form, we assume that housing prices rise with increasing distance to its nearest industrial site. More specifically, the sign and the magnitude of estimated coefficients of the separate distance dummies are, respectively, expected to be negative and decreasing at a decreasing rate as distance between the site and the property increases (i.e., the coefficients under consideration express the price differentials between the concerned distance category concerned and the reference group).[14] Furthermore, everything constant, an increase in housing prices is hypothesized to result from increases in floor area and housing volume. Increases in the age of the dwelling are hypothesized to cause a decline in housing values. The price effect associated with the style of housing (i.e. free-standing, semi-detached, terraced or apartment) is uncertain given the fact the model controls for floor area and volume. Specific assets of a house, like the presence of central heating, garage and garden, are expected to have a positive price effect. Neighbourhood measures associated with status, such as ethnical composition and population density, are expected to influence housing prices negatively, as amongst others has been shown by Rouwendal and Van der Straaten (2008).

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[12] Details are available upon request.

[13] When spatial dependencies are present, OLS estimates may yield biased or inefficient estimates (Anselin, 1988). Spatial dependencies can affect hedonic pricing studies due to either structural relationships among the observations or due to the omission of spatially correlated explanatory variables that impact the spatial dependency among the error terms. We refrain from estimating a spatial lag or spatial error model for three reasons. The first is because of computational problems; computer capacity is equipped to process a sample of around 10,000 observations at its maximum. Furthermore, previous studies have failed to find compelling qualitative differences between hedonic models with and without measures of spatial autocorrelation (Deaton and Hoehn, 2004). Finally, coefficients of the explanatory variables estimated by spatial autocorrelation models hardly differ from those obtained by OLS (see, for example, Neupane et al., 2007; Rouwendal and Van der Straaten, 2008).

[14] Our results may be biased due to a possibly negative correlation between distance to the industrial sites and distance to, for example, public goods provided in city centre. This problem becomes more severe in case many industrial sites are located at the urban fringe. This bias is likely to be limited in our case because (i) our sample comprises both inner-city industrial sites as well as fringe sites (e.g. greenfield sites), and (ii) we control in our empirical analysis for a range of characteristics of city-centres that may positively affect house prices, thus reducing the bias due to an omitted variable (viz. distance to 'goods' typically provided in city centres such as railway stations and employment).

Considering the distance to jobs, we hypothesize a positive effect on housing value. Decreased remoteness of households to areas of employment should reduce the costs of commuting and the associated savings will be capitalized into property values and potentially results in higher prices. Following Debrezion et al. (2006), we suppose that the effect of increasing distance to highway exits and railway stations on housing price is negative. Increased proximity causes positive effects in terms of accessibility which are assumed to exceed the negative effects concerned, like inherent traffic nuisance. Since the Randstad is the economic core region of the Netherlands, dwellings located in this region are hypothesized to sell at a higher price than dwellings in Noord-Brabant. The remainder of the variables which are associated with the perceived impact proceeding from present industrial sites on housing values, such as the size of the industrial site, and heavy sites compared with regular sites, are hypothesized to affect housing prices negatively.

6. Empirical results

6.1 Basic results

The basic estimation results are shown in Table 1. The majority of the results are highly statistically significant (at a 1% significance level) and consistent with our hypotheses, including those for the distance-to-site dummies. Looking at the industrial site characteristics size and type of site, we see that the corresponding estimated parameters have a negative and positive sign, respectively. This confirms on the one hand our hypothesis that the larger an industrial site, the more inconvenience it generates. On the other hand, the effect of heavy sites on its direct vicinity has significantly less impact than regular sites, which is remarkable since the heavy-industry sites are defined as industrial sites which intend to establish highly undesirable effects in terms of environmental nuisance (see Section 4). A possible explanation for this unexpected finding is the relative small occurrence of sites denoted as 'heavy' in our data set. It may also stem from an omitted variable bias (for example, lot sizes close to heavy sites being relatively large).

Considering distance, we find consistent with expectations that increased remoteness to industrial sites increases housing prices. Houses located within 250 metres from a site are predicted to sell at 14.9 per cent less than houses located beyond a distance of 2,250 metres from an industrial site (the reference group), ceteris paribus. The estimated relationship, employing the linear piecewise distance specification and a given set of characteristics, is shown in Figure 2. The figure illustrates the value of the representative property[15] as a function of the distance-to-site dummy (keeping all other variables constant).

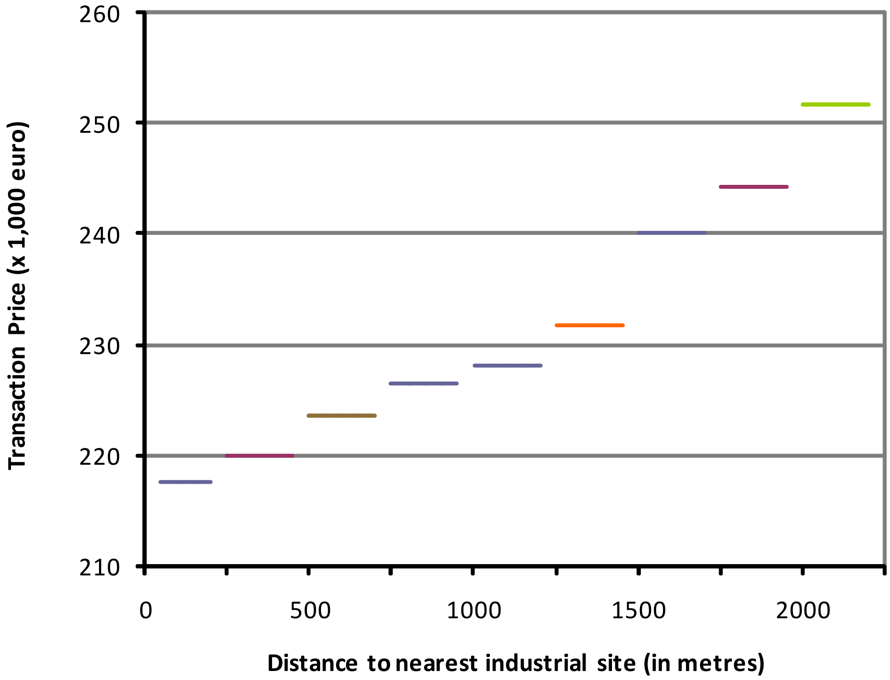
[15] The representative property is defined as the hypothetical property for which all explanatory variables (viz. attributes of the property), except for the distance to the industrial site, are set at their respective means.

Table 1. Estimation results of the hedonic price function for the Randstad and Noord-Brabant in 2005 using a piecewise specification of distance

Variable	Coefficient	t-statistic
Constant	9.649***	(260.4)
Structural characteristics (S_k)		
Ln Floor area (m^2)	0.391***	(29.1)
Ln Volume (m^3)	0.407***	(29.4)
Free-standing	0.275***	(46.0)
Semi-detached	0.128***	(27.4)
Terraced	–0.022***	(–7.0)
Year of construction (<1906)	–0.008*	(–1.7)
Year of construction (1906-1930)	–0.086***	(–24.2)
Year of construction (1931-1944)	–0.126***	(–32.1)
Year of construction (1945-1959)	–0.157***	(–42.9)
Year of construction (1960-1970)	–0.175***	(–71.6)
Year of construction (1971-1980)	–0.155***	(–65.8)
Year of construction (1981-1990)	–0.099***	(–41.7)
Central heating	0.081***	(21.9)
Garage	0.094***	(36.0)
Garden	–0.000	(–0.0)
Neighbourhood characteristics (N_l)		
Ethnical minorities (fraction population)	–0.644***	(65.3)
Ln Population-density (inhabitants per km^2)	–0.021***	(–16.2)
Ln Distance to 100,000 jobs (in metres)	–0.096***	(–51.4)
Ln Distance to highway exit (in metres)	–0.019***	(–12.7)
Ln Distance to railway station (in metres)	–0.012***	(–13.0)
Noord-Brabant regional dummy	–0.137***	(–72.9)
Industrial site characterises (I_m)		
Ln Gross area of nearest industrial site	–0.012***	(–19.1)
Heavy industrial site dummy	0.117***	(30.6)
Distance (D_n)		
0-250	–0.149***	(–21.4)
250-500	–0.139***	(–20.1)
500-750	–0.122***	(–17.5)
750-1000	–0.109***	(–15.5)
1000-1250	–0.103***	(–14.2)
1250-1500	–0.087***	(–11.5)
1500-1750	–0.051***	(–6.3)
1750-2000	–0.034***	(–3.9)
2000-2250	–0.004	(–0.4)
Adjusted R^2	0.774	
Number of observations	70,684	

Notes: The equations also contains month of sale (full estimation results are available upon request); White *t*-values are given in parentheses; *** Significant at the 1% level; * Significant at the 10% level.

Figure 2. Transaction price gradient function for a representative property (piecewise specification of distance)



In Figure 2, the depicted pattern suggests that the partial relationship between distance to industrial site and housing prices can be represented by a logistic function. We therefore proceed by replacing the piecewise specification of distance with a logistic functional form of distance. More specifically, we estimate the following model using nonlinear squares (NLS):

$$LnP_j = \alpha + \sum_{k=1}^{15} \beta_k S_{j,k} + \sum_{l=1}^{6} \gamma_l N_{j,l} + \sum_{m=1}^{2} \delta_m I_{j,m} + \eta_1 \frac{e^{\eta_2 + \eta_3 Ln(D_j)}}{1 + e^{\eta_2 + \eta_3 Ln(D_j)}} + \varepsilon_j , \tag{5}$$

where all variables are defined as in Equation (1). Due to the use of the logistic specification for distance, we obtain three estimated parameters, η_1, η_2 and η_3, which characterize the partial relationship between distance and the housing price. It is expected, given the nature of the logistic function, that the relationship follows an 'S-curve': an exponential increase of transaction prices in the direct vicinity of an industrial site followed by an exponential decay. Adopting this more parsimonious functional form results in a reduction of parameters to be estimated, and hence an increase in degrees of freedom.

The results of the estimation are presented in Table 2. Since the other estimated coefficients remain generally unchanged, we only report the outcomes referring to the effect of distance to an industrial site on housing prices.

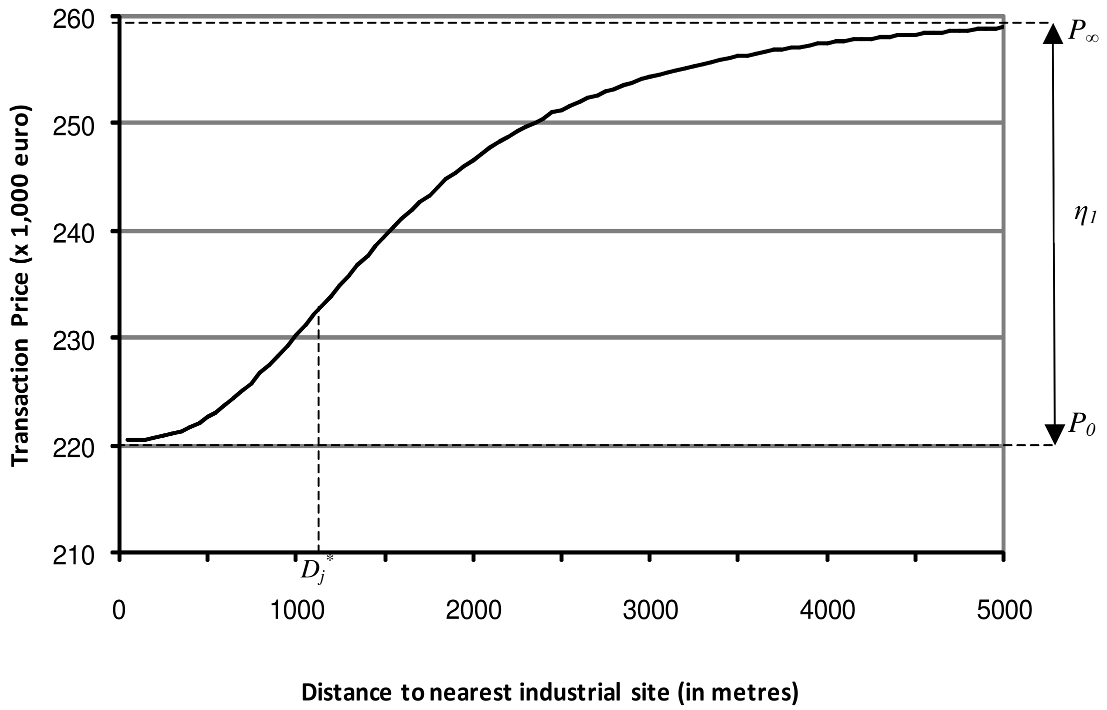
Table 2. Estimation results of the hedonic price function for the Randstad and Noord-Brabant in 2005 using a logistic specification of distance

Variable	Coefficient	t-statistic
Constant	9.506***	(261.7)
Distance (D_j)		
η_1	0.169***	(8.8)
η_2	–18.445***	(–10.7)
η_3	2.516***	(9.6)
Adjusted R^2	0.774	
Number of observations	70,684	

Notes: Only the estimation results referring to the effect of distance are reported (full estimation results are available upon request); White *t*-values are given in parentheses; *** Significant at the 1% level.

The implications of the obtained estimates for the actual relationship between distance and housing prices can best be illustrated graphically (see Figure 3). It illustrates the value of the representative property[16] given a change in the distance-to-site variable, holding the other variables constant.

Figure 3. Transaction price gradient function for a representative property (logistic specification of distance)



The revealed shape of the curve in Figure 3 is in accordance with our expectations. It illustrates that the impact of negative externalities stemming from industrial sites are largely localized. Increasing remoteness leads to a gradually diminishing increase of housing prices. With reference to the

[16] The representative property is defined as the hypothetical property for which all explanatory variables (viz. attributes of the property), except for the distance to the industrial site, are set at their respective means.

goodness-of-fit and the parsimony of the preceding models, examination of corresponding criteria does not point at one of the models being clearly preferred over the other[17] However, given the advantages with respect to interpretation and presentation, we decide to use the more parsimonious model to elaborate upon the relationship between distance to industrial site and housing prices.

A more detailed look at the logistic function of housing price with respect to the minimum distance to its nearest industrial site gives us more precise information about the nature of the distance-decay of the negative externalities which stem from the industrial sites concerned. The partial relationship between housing prices and distance to nearest industrial site can be represented as:

$$P(D_j) = 0.169 \frac{e^{-18,445+2.516\,Ln(D_j)}}{1+e^{-18.445+2.516\,Ln(D_j)}} = \frac{0.169\,e^{-18,445}\,D_j^{\;2.516}}{1+e^{-18,445}\,D_j^{\;2.516}}. \tag{6}$$

The parameter η_1 captures the maximum variation of housing prices as a function of distance to the nearest industrial site (see Figure 3). The relationship is upward sloping if $\eta_1 \cdot \eta_3 > 0$. The point of inflection (viz. the distance at which the curve is steepest, and thus beyond which the effect of industrial site presence gradually diminishes) can be derived as:

$$D_j^{\;*} = \left(\frac{\eta_3 - 1}{e^{\eta_2}(1+\eta_3)} \right)^{1/\eta_3}. \tag{7}$$

The point of inflection thus decreases with increasing values of η_3. In the case depicted in Figure 3, the point of inflection (D_j^*) is at 1,093 metres. Up to this distance, the housing prices are increasing at an increasing rate, whereas the housing prices are increasing at a decreasing rate beyond this distance. We refer to Appendix B for technical details.

6.2 A more detailed look at industrial site size

In view of the estimation results of Equation (5), we infer that the nature of the distance-decay of negative externalities stemming from industrial sites is largely localized. We have, amongst others, seen that the point of inflection is 1,093 metres. However, we have neglected the potential relevance of the interplay between the effect of distance and another relevant industrial site characteristic such as the gross area of the site.

The value of the estimated coefficient of the gross area of the nearest industrial site, irrespective of which model we use, equals –0.012 (statistically significant at a 1% level). This implies

[17] The adjusted R^2 of both models is 0.774. The Aikake's Information Criterion (AIC) for the distinguished models equals –0.251 for the piecewise model, and –0.250 for the logistic model. The model with a lower AIC is typically preferred.

that an increase of 1 per cent of the gross area of the nearest industrial site decreases housing price by 0.012 per cent. However, it is plausible to contend that the effect of the increase of site area on housing prices modifies with increasing distance from the site concerned. We therefore allow for interaction effects between gross site area and distance to the nearest site. Interaction of these parameters with industrial site acreage will result in a change of the nature of the distance decay in that it becomes conditional on site acreage. Sequential regression model runs (NLS) for separate 'site size-distance' interaction terms, and all three site size-distance interaction terms together, however, only yield statistically significant estimates (at a 5% level) for the model which controls for $\eta_1 \cdot LnGrossarea$ (φ_1) .[18] This model is specified as follows, where all variables are defined as in Equation (5):

$$LnP_j = \alpha + \sum_{k=1}^{15} \beta_k S_{j,k} + \sum_{l=1}^{6} \gamma_l N_{j,l} + \sum_{m=1}^{2} \delta_m I_{j,m} + \eta_1 \frac{e^{\eta_2 + \eta_3 Ln(D_j)}}{1 + e^{\eta_2 + \eta_3 Ln(D_j)}}$$
$$+ \varphi_1 (\eta_1 \cdot LnGrossArea_j) \frac{e^{\eta_2 + \eta_3 Ln(D_j)}}{1 + e^{\eta_2 + \eta_3 Ln(D_j)}} + \varepsilon . \qquad (8)$$

The results of the estimation are presented in Table 3. We only report the outcomes referring to the effects of site size, distance to an industrial site, and corresponding interaction effect on housing prices.

Table 3. Estimation results of the hedonic price function for the Randstad and Noord-Brabant in 2005 using a logistic specification of distance: the interaction effect between distance and industrial site size

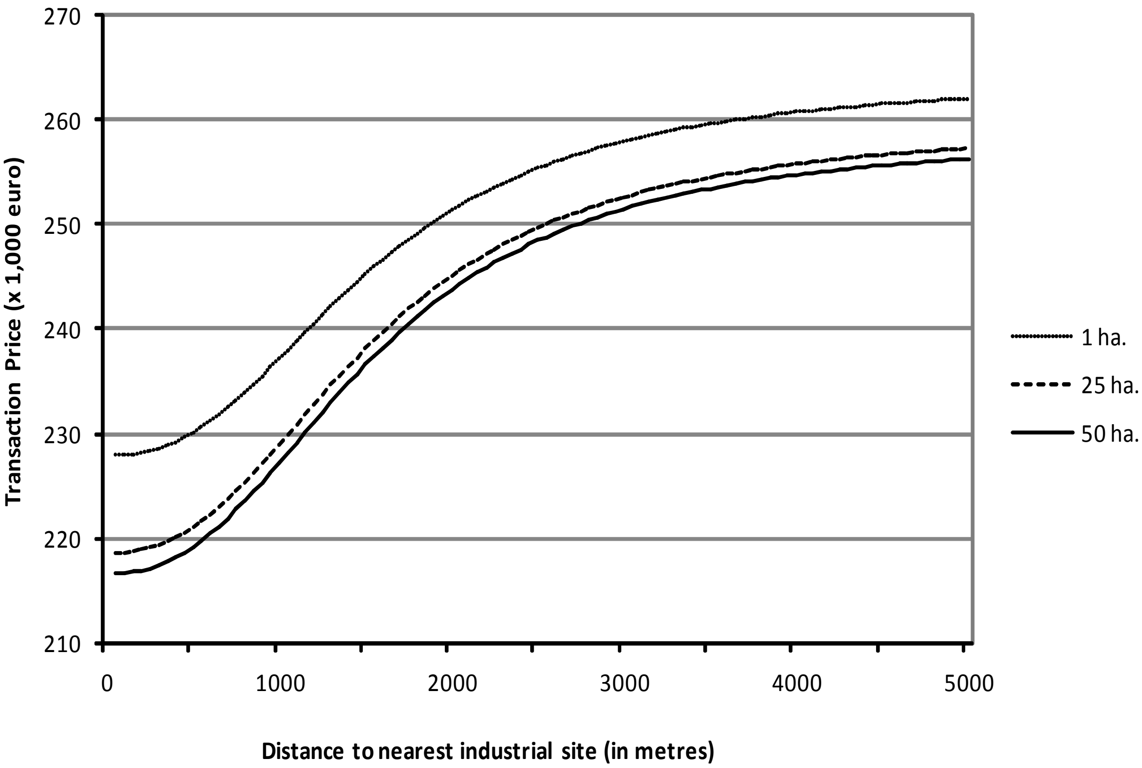
Variable	Coefficient	t-statistic
Constant	9.511***	(261.7)
Size of nearest industrial site		
Ln Gross area	–0.013	(15.6)
Distance		
η_1	0.147***	(7.5)
η_2	–17.700***	(–10.6)
η_3	2.419***	(9.4)
Interaction distance and size		
ϕ_1	0.008**	(2.3)
Adjusted R^2	0.774	
Number of observations	70,684	

Notes: Only the estimation results referring to the (interaction) effects of distance are reported (full estimation results are available upon request); White *t*-values are given in parentheses; *** Significant at the 1% level; ** Significant at the 5% level.

[18] The estimation results of the other models which are related to the interaction between site size and distance are available upon request to the authors.

The estimated interaction coefficient (φ_1) indicates that the effect of distance on housing prices, referring to the range, rises with increasing site size. In other words, an increase of 1 per cent gross area of the industrial site concerned elevates the accompanying distance effect with 0.008 per cent, ceteris paribus. This effect is illustrated graphically in Figure 4. We have depicted the price gradients of representative properties[19] which nearest industrial site comprise a gross area of 1 hectare, 25 hectares and 50 hectares, given a change in the distance-to-site variable. Besides that the overall price-level of houses located near 'small' industrial sites exceeds the price level of 'larger' sites, we observe that the range or variation of the housing prices increases as the size of the nearest industrial site increases. Furthermore, the relationship between site size and distance to the site appears to be nonlinear, as the effect of site size with respect to distance has a relative large impact on housing price as it concerns the expansion of a relatively small site vis-à-vis the expansion of a relatively large site.

Figure 4. Transaction price gradient functions for various representative properties for different site sizes (logistic specification of distance)



6.3 Robustness analysis

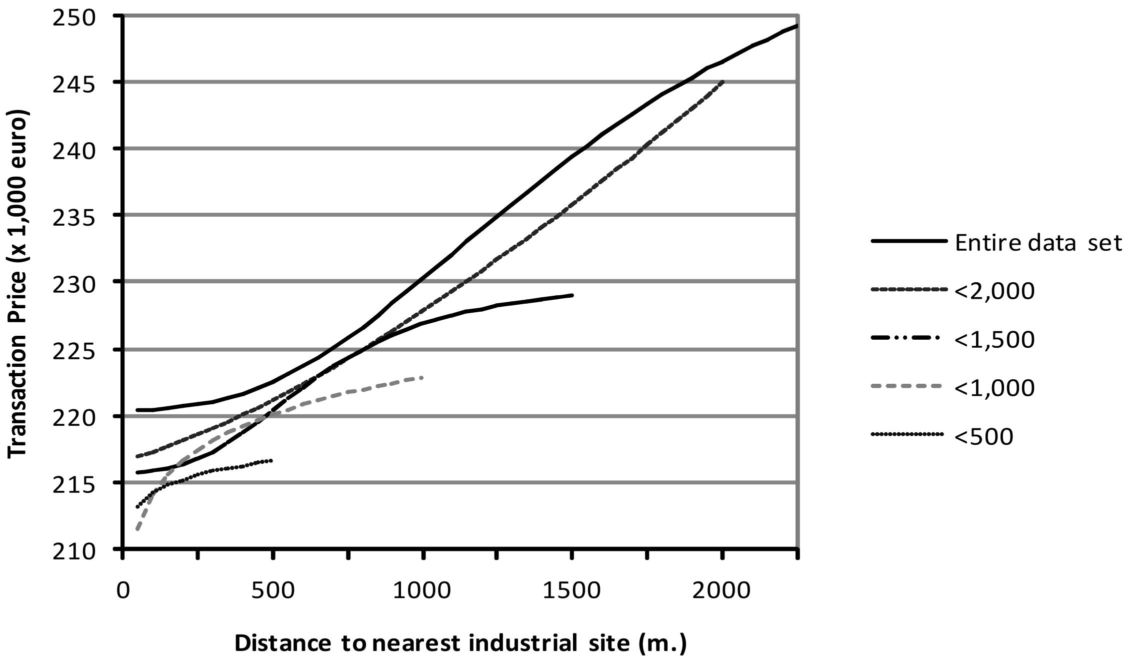
The results so far show that the findings concerning the marginal effect of industrial site presence on housing prices, as measured by distance-to-site, are robust to the employed functional forms, viz. piecewise and logistic specification of distance. In accordance with our findings concerning goodness-

[19] The representative property is defined as the hypothetical property for which all explanatory variables (viz. attributes of the property), except for the distance to the industrial site, are set at their respective means.

of-fit and parsimony of the model (see Section 6.1); we prefer to use the logistic functional form. In order to test the robustness of our results, we have replicated the corresponding regression model employing different subsets of the original data, and finally, we have added municipality dummies to the basic model to examine whether the results are sensitive to potential unobserved local circumstances.

First, we have conducted model runs for four different subsets comprising houses which are, respectively, located within 500, 1,000, 1,500 and 2,000 metres from the nearest industrial site.[20] The regression estimates are strongly in line with the findings discussed before[21]: they confirm the lack of variation in housing prices within short distance from an industrial site, and conversely, expanding the sample sizes leads to a rise of housing prices variation across distance. The 500 metres and 1,000 metres samples are characterized by insignificant estimates with respect to distance-to-site, whereas (highly) statistically significant results are found for the 1,500 and 2,000 samples. Accordingly, Figure 5 shows that housing prices are slightly affected within the ranges of 500 metres and 1,000 metres, unlike housing prices within the ranges of 1,500 and 2,000 metres.

Figure 5. Transaction price gradient functions for different representative properties (logistic specification of distance), based on various sub samples



An alternative analysis examines the sensitivity of the empirical results to regional specifications. Therefore, the transaction data has been divided into two sub samples, restricting the analysis to the

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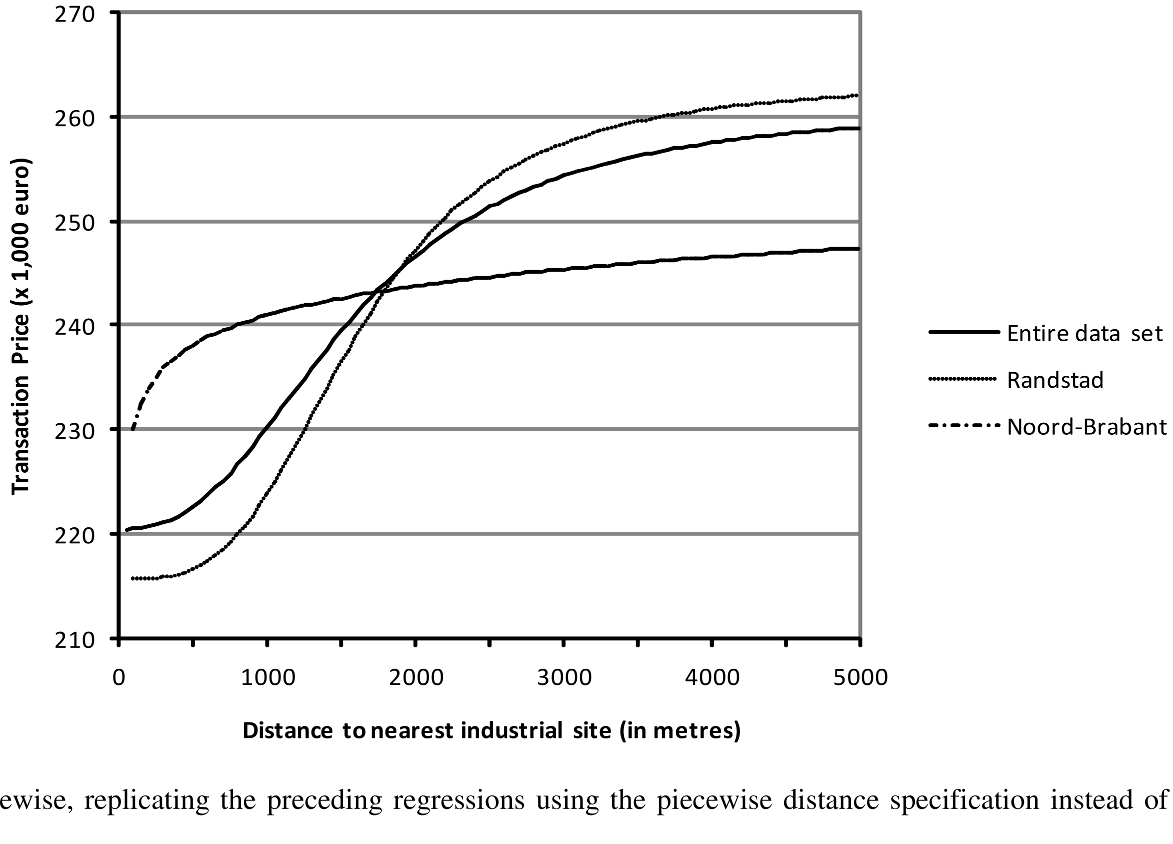
[20] Sampling along the spatial dimensions concerned creates data sets consisting of the following number of observations: <500: *N*=27,711; <1,000: *N*=50,660; <1,500: *N*=62,485; <2,000: *N*=67,600.
[21] The remainder of the estimation results related to the sensitivity analyses are available upon request from the authors.

Randstad and Noord-Brabant, respectively.[22] The model run for the Randstad subset yields coefficients which are fully consistent with the general findings, regarding sign as well as statistical significance of the estimated effects. However, the impact of industrial site presence on housing prices appears to be more pronounced in the Randstad region than in the entire area of examination, in the sense that housing prices are increasing at a faster rate as the distance to the nearest industrial site increases. For the sake of comprehensibility, these outcomes have been displayed graphically (see Figure 6). Conversely, the results for Noord-Brabant with regard to distance yield statistically insignificant outcomes. Displaying the corresponding transaction price gradient reveals a relationship between distance and housing price which exhibits a logarithmic form.[23] In Noord-Brabant the effect of industrial site presence on housing prices is, apparently, manifested within relatively short distance of the site concerned. Beyond a distance of approximately 1,000 metres there is no discernible impact of distance to the closest site on the housing price level. This may be caused by the difference in regional housing markets.

Figure 6. Transaction price gradient functions for different representative properties (logistic specification of distance), based on regional sub samples



Likewise, replicating the preceding regressions using the piecewise distance specification instead of

[22] Sampling along the regional dimensions concerned creates data sets consisting of the following number of observations: Randstad: N=51,689; Noord-Brabant: N=18,995.

[23] This has been confirmed by running an alternative regression (OLS) using the natural logarithm of distance. The regression yields statistically significant estimates of the log of distance (at a 1% significance level). Estimation results are available upon request of the authors.

the logistic distance specification yields consistent results, indicating that the employed model is sensitive to geographical considerations.[24]

Finally, estimating the basic model with inclusion of 219 municipality dummies, each corresponding to the municipality in which the dwelling concerned is located (taking the municipality of Amsterdam as reference group), yields outcomes which are qualitatively as well as quantitatatively comparable to those obatined with the basic logistic specification (see Table 4). Considering the estimated partial relationship between distance to industrial site and housing prices, the parameter η_1, which captures the maximum variation of housing prices as a function of distance to the nearest industrial site, slightly increases from 0.169 to 0.186. Furthermore, by using Equation (7) the point of inflection equals 1,133 metres (instead of 1,093 metres). The remainder of the estimated coefficients are also consistent with the basic model estimates. Hence, we may infer that the revealed effect of distance-to-site on housing prices is robust in the sense that its nature is hardly affected by potential unobserved heterogeneity, stemming from specific local circumstances.

Table 4. Estimation results of the hedonic price function for the Randstad and Noord-Brabant in 2005 including municipality dummies

Variable	Coefficient	t-statistic
Constant	9.510***	(232.6)
Distance (D_j)		
η_1	0.186***	(2.7)
η_2	–13.006***	(–8.0)
η_3	1.653***	(5.8)
Adjusted R^2	0.839	
Number of observations	70,684	

Notes: Only the estimation results referring to the effect of distance are reported (full estimation results are available upon request); White *t*-values are given in parentheses; *** Significant at the 1% level.

7. Conclusion

The main aim of this paper is to study the impact of the presence of industrial sites on its direct vicinity. Applying a hedonic pricing model, we value the negative externalities generated by activities located on industrial sites in the Randstad region and the province of Noord-Brabant (both located in the Netherlands), in the year 2005. The effect of these negative externalities is proxied by estimation of the distance-decay of housing prices in the vicinity of industrial sites. In accordance with previous hedonic pricing studies, our results clearly show that the presence of an industrial site has a statistically significant negative effect on the value of residential properties: housing prices rise with increasing distance to its nearest industrial site. However, in contrast to previous hedonic pricing studies that we know of, we employ a logistic functional form to reveal the nature of the effect of

[24] The estimation results related to the sensitivity analysis are available upon request to the authors.

distance-to-site on housing prices. This leads to a relationship between distance and residential property prices which is best described as ‘dichotomous’: relatively close to a site, negative externalities have a strong hampering effect on housing prices which convexly decreases up to a certain distance. Beyond this point, in our case 1,093 metres, the hampering effect on housing prices concavely decreases till it fades out with increasing distance. Furthermore, we find that the effect of site size intervenes with the effect of distance on housing price, in the sense that this interactive effect affects the maximum variation of the distance effect: the larger the site, the larger the range of houses which are affected by the presence of the industrial site concerned.

Our outcomes demonstrate that the impact of negative externalities is largely localized, implying that the perception of the spatial quality of the neighbourhood is affected by the presence of an industrial site, and to a certain extent by the size of an industrial site. In addition, it may provide spatial planners more insight into setting zoning guidelines in order to decrease potential inconvenience stemming from industrial site. We have to be careful, however, in deriving inferences with regard to the latter, as our study only employs revealed preferences of house buyers in the vicinity. In view of this, we should take into account that our approach is sensitive to selectivity in willingness to accept a disamenity concerning residential location decisions. This may be manifested by underestimation of the distance-to-site effect within short distance of an industrial site. Our results, furthermore, neglect the preferences of other stakeholders, for instance employees of the firms located on the sites or the visitors of these firms, which may attach different values to the impact of industrial sites. Another possible shortcoming is the variation across regions. As we obtain substantial different parameters regarding the effects of distance on housing price for the Randstad and Noord-Brabant subsets, it reduces the general applicability of the method. This sensitivity with respect to regional demarcation may be of special importance for policymakers.

Hence, the findings provide us insight into the extent of negative externalities involved with location of certain industrial activities on a specific site. The observed impacts address the notion of spatial quality of an industrial site. Despite some caveats, they provide useful information that can help prioritizing and assessing spatial planning approaches.

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Appendix A. Definitions, sources and descriptive statistics (*N*=70,684)

Variable	Description	Source[25]	Mean	Standard Deviation
Price	Transaction price in the year 2005 in euros	NVM	254,522.33	141,377.12
Structural characteristics				
Floor area	Size of living area of the house (m^2)	NVM	120.24	49.51
Volume	Volume of the house (m^3)	NVM	353.28	220.34
Free-standing	Dummy variable: equals one if the house is free-standing	NVM	0.08	0.27
Semi-detached	Dummy variable: equals one if the house is semi-detached	NVM	0.10	0.31
Terraced	Dummy variable: equals one if the house is a terraced house	NVM	0.46	0.50
Apartment	Dummy variable: equals one if the house is an apartment	NVM	0.36	0.48
Before 1906	Dummy variable: equals one if the house has been built before 1906	NVM	0.06	0.24
1906-1930	Dummy variable: equals one if the house has been built in the period 1906-1930	NVM	0.14	0.34
1931-1944	Dummy variable: equals one if the house has been built in the period 1931-1944	NVM	0.09	0.28
1945-1959	Dummy variable: equals one if the house has been built in the period 1945-1959	NVM	0.08	0.26
1960-1970	Dummy variable: equals one if the house has been built in the period 1960-1970	NVM	0.15	0.36
1971-1980	Dummy variable: equals one if the house has been built in the period 1971-1980	NVM	0.15	0.36
1981-1990	Dummy variable: equals one if the house has been built in the period 1981-1990	NVM	0.14	0.35
After 1990	Dummy variable: equals one if the house has been built after 1990	NVM	0.20	0.40
Central heating	Dummy variable: equals one if the house has central heating	NVM	0.92	0.27
Garage	Dummy variable: equals one if the house has a garage	NVM	0.20	0.40
Garden	Dummy variable: equals one if the house has a garden	NVM	0.56	0.50
Neighbourhood characteristics				
Ethnical minorities	Fraction of inhabitants of non-western origin in the ZIP-code area (4-digit) of the house	CBS	0.12	0.11
Population-density	Number inhabitants per km^2 in the postcode area (4-digit) of the house	CBS	5,361.07	3,935.07
Distance to highway exit	Distance, by road, from the house to the nearest highway exit (in metres)	NWB	3,993.81	2,548.18
Distance to railway station	Straight-line distance from the house to the nearest railway station (in metres)	NS	3,142.00	3,279.79
Job accessibility	Minimum distance (circle radius) within which a total of 100,000 jobs can be reached (in metres)	RPB/LS	8,492.26	4,511.54
Noord-Brabant	Dummy variable: equals one if the house is located in the province of Noord-Brabant	NVM	0.27	0.44

[25] CBS: Statistics Netherlands; IBIS: Dutch Industrial Sites Database; LS: Land Use Scanner NS: Dutch Railways; NVM: Dutch Association of Real Estate Agents; NWB: National Road Database; RPB; Netherlands Institute for Spatial Research.

Variable	Description	Source	Mean	Standard Deviation
Industrial site characteristics				
Distance to industrial site	Straight-line distance from the house to the boundary of the nearest industrial site (in metres)	IBIS	784.39	606.72
Gross area	Gross area of the nearest industrial site (in hectares)	IBIS	34.02	58.45
Regular industrial site	Dummy variable: equals one if the nearest industrial site concerns a miscellaneous or high-tech site	IBIS	0.93	0.27
Heavy industrial site	Dummy variable: equals one if the nearest industrial site concerns a heavy industry site, sea harbour or transport site	IBIS	0.07	0.27

Appendix B. Characteristics of housing prices as a function of distance in the case of a logistic function

We start from the basic function:

$$F(D_j) = \eta_1 \frac{e^{\eta_2 + \eta_3 LnD_j}}{1 + e^{\eta_2 + \eta_3 LnD_j}} = \frac{\eta_1 e^{\eta_2} D_j^{\eta_3}}{1 + e^{\eta_2} D_j^{\eta_3}} \tag{B.1}$$

The first-order derivative of this function (*F*) with respect to distance (*D*) equals:

$$F'(D_j) = \frac{\eta_1 \eta_3 e^{\eta_2} D_j^{\eta_3 - 1}}{(1 + e^{\eta_2} D_j^{\eta_3})^2} \text{, so } F'(D_j) > 0 \text{ if } \eta_1 \cdot \eta_3 > 0 \tag{B.2}$$

The second-order derivative equals:

$$F''(D_j) = \frac{(1 + e^{\eta_2} D_j^{\eta_3}) D_j^{\eta_3 - 1} e^{\eta_2} \eta_3 \eta_1}{(1 + e^{\eta_2} D_j^{\eta_3})^4} \text{, so } F''(D_j) = 0 \text{ if } D_j^* = \left(\frac{\eta_3 - 1}{e^{\eta_2} (1 + \eta_3)} \right)^{1/\eta_3} \tag{B.3}$$

For $0 < D_j < D_j^*$, $F(D_j)$ is an increasing convex function of D_j, if $\eta_3 > 0$. For $D_j^* < D_j < \infty$, $F(D_j)$ is an increasing concave function of D_j, if $\eta_3 > 0$.